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Age and binding within-dimension features in visual short term memory

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Abstract

Older adults have difficulties in binding information in long term memory (e.g. objects with colours). The effect of age on visual short term memory (VSTM) binding is less well understood. Recent evidence has suggested that older adults' VSTM for colours bound to shapes or for locations bound in configural representations may be preserved. In two experiments we investigated whether this lack of an age effect on VSTM for bound features can be reproduced when features are drawn from the same dimension (i.e. colour-colour binding) and when spatial clues are not available. Younger and older adults were presented with two sequential arrays of unicoloured or bicoloured objects and their accuracy in detecting changes between arrays was used as the measure of memory performance. Memory was assessed using a change detection paradigm for unicoloured objects and for bicoloured objects with changes in colour conjunctions (i.e. colours swapping between objects) or with changes in non-conjunctive colours (i.e. colours replacing colours in the study array). Both young and older adults were less accurate at remembering objects defined by colour conjunctions than unicoloured objects or objects composed of two non-conjunctive colours (Experiment 1). Increasing task demands in terms of memory and perceptual load had no greater effect on the older than the younger adults (Experiment 2). We suggest (1) that colours were not integrated into single units in VSTM; (2) that remembering the binding between colours has a cost; and (3) that neither of these effects are age-dependent.

Introduction

The ability to bind information at a perceptual level is preserved in ageing once factors affecting older adults such as sensory limitations or slow processing speed are controlled (e.g. by improving object discriminability, reducing perceptual load, or increasing presentation times) [1,2].

The mechanisms responsible for associating information in memory, however, are affected by age [3,4]. This age-related associative memory deficit manifests as an impairment in long term memory (LTM) in older adults for events defined by combined elements such as objects and locations [3,5], faces and names [4,6], or pairs of words [7,8]. Chalfonte and Johnson [3] asked younger and older adults to study arrays of coloured objects presented in different locations for 90 sec. Participants then had 90 sec to recognize individual features of the studied items (i.e. objects, colours, or locations only) or their combinations (i.e. object-colour or object-location). Older adults' memory for combined features was found to be poorer than that of younger adults. The authors concluded that age seems to impair the ability to retain the relatedness of items in LTM. However, a recent study [9] investigating binding in visual short term memory (VSTM) with younger adults has shown that associations formed in short-term change detection tasks are replaced by the study array on the next trial, leaving no residual memory trace or evidence of learning across trials. This was true even when exactly the same study array was used on every trial. Therefore, bindings were retained only for the duration of a single trial. This indicates that holding temporary bindings in memory might rely on different cognitive functions than does the learning of bindings between features.

This temporary binding process might be differentially sensitive to the effects of age. Moreover, within VSTM, the effect of age on binding information is poorly understood. Older adults have shown difficulties in maintaining bindings of common objects and locations [10,11] or colours and locations [12]. The effect of age on binding to location was challenged by Olson et al. [13] who showed no age-related deficits at very brief delays. They concluded that older people's ability to use location information is preserved either when they have to intentionally bind several spatial locations in a configural representation or when items are incidentally bound to location. It might hence be argued that the intentional representation of short-term bindings of features processed within a single dimension (e.g. location to location) is less affected by age than the intentional representation of short-term bindings of features between different dimensions (e.g. objects to locations). However, Brockmole, Parra, Della Sala and Logie [14] found no effect of age on the intentional STM binding of shapes with colours. Older adults performed more poorly overall than younger adults, but this was true to the same extent for integrated objects or single features. The authors concluded that age did not have a differential effect on memory for shapes and colours bound in an object-based representational format in VSTM compared with memory for single features.

Brockmole et al. [14] investigated between-dimension feature binding in VSTM whereas Olson et al. [13] reported that binding in STM of locations to locations or the incidental use of location as the to-be-bound feature were also unaffected by age. However, configural binding among a set of locations may significantly reduce memory load by allowing the representation of spatial configurations as visual patterns (see Cowan et al. [12] for a similar criticism). This would in turn increase the likelihood of

binding under low memory load (i.e. fewer spatial locations) but it would be less likely or efficient under high memory load. Olson et al. [13] reported (Experiment 1) that when six items were presented older people were relatively less accurate and significantly slower than younger adults as compared to when three items were displayed. One other caveat is that in Olson et al.'s [13] Experiment 2 location was incidentally encoded as it was a feature irrelevant to the task. Impairments in STM binding have been observed in older adults with tasks requiring the intentional binding of objects or colours to location and where no configural clues are available (e.g. by using sequential presentation or larger set sizes) [10,12].

We aimed to clarify the issue of possible age-effects in VSTM binding by capitalising on a task which investigates the intentional within-dimension binding of colour to colour, with location information irrelevant to the task [15-17]. This task has been extensively employed in the literature with young participants. However, memory for bicoloured objects have never been used to assess the effects of ageing on within-dimension feature binding in STM.

Experiment 1

First, we investigated whether or not age has a specific impact on VSTM performance for conjunctions of colours within an object as compared to VSTM performance for individual colours. Second, we assessed whether age had an effect on the cost of remembering the precise binding of colours presented as parts of bicoloured objects, or whether any age effect depends on memory load (i.e. number of colours). We predicted

that if colours are treated in VSTM as surface features of bicoloured objects, age would not affect this binding process [14], and the expected cost of holding in VSTM bicoloured objects as compared to unicoloured objects will be equivalent in younger and older adults.

Methods

Participants for Experiment 1 were 14 young (age: $M=20.7$, $SD=1.3$) and 14 older adults (age: $M=65.9$, $SD=5.9$). The groups were matched for Verbal IQ as measured by the Wechsler Test of Adult Reading (WTAR) [18] (young: $M=114.2$, $SD=4.3$; older: $M=113.0$, $SD=2.0$). Participants described themselves as healthy at the time of the assessment. Additionally, participants who scored above 2 in the Ishihara Colour Blindness Test were excluded. All participants consented to take part in this study.

A change detection task presented participants with arrays of three object shapes in random positions on a 15" PC screen using a 3x3 virtual grid. At the viewing distance of 65 cm, objects subtended 0.75° and the minimum distance between them was 0.5° . Objects were constructed using six different object shapes, each defined by a figure and ground area (see Fig. 1A). The figure or ground area of each object (each representing 50% of the surface) was filled with a colour. A set of 18 colours was first given to a group of 20 participants with a mean age of 28.25 years ($SD = 7.17$). In order to make these colours more difficult to name, their CIE values [19] were changed to generate non-basic colours. Participants observed pairs of colours on the screen and they made speeded decisions as to whether the pairs consisted of the same or different colours. Colours from combinations resulting in correct response times below the lower bound of the confidence

interval at 95% were selected (see <http://hdl.handle.net/1842/2441> for CIE values and luminance in lm/m^2 of the eight colours that matched this criterion as well as the set of object shapes used in this study). This piloting of materials ensured that the colours were easy to discriminate visually, but could not readily be remembered in terms of their colour names. Pilot studies carried out by our group and others [15] also showed no differences in performance across the different object shapes.

Trials began with a fixation screen for 250 msec. This was followed by a study display presented for 2000 msec (Fig. 1A). After an unfilled retention interval of 900 msec, the test display was presented until participants responded. There was then a gap of 1000 msec until the next trial. In half of the trials objects on both displays were the same. In the other half, two of the objects in the test display showed different colours from those in the study display. Object locations in the test display were always randomly changed to make location irrelevant to the task. Participants were requested to detect whether the study and test displays consisted of the “same” or “different” items and to respond verbally accordingly. Participants performed 15 practice trials followed by 32 test trials in each experimental condition. The “same” and “different” trials were fully randomized, conditions were blocked and counterbalanced across participants.

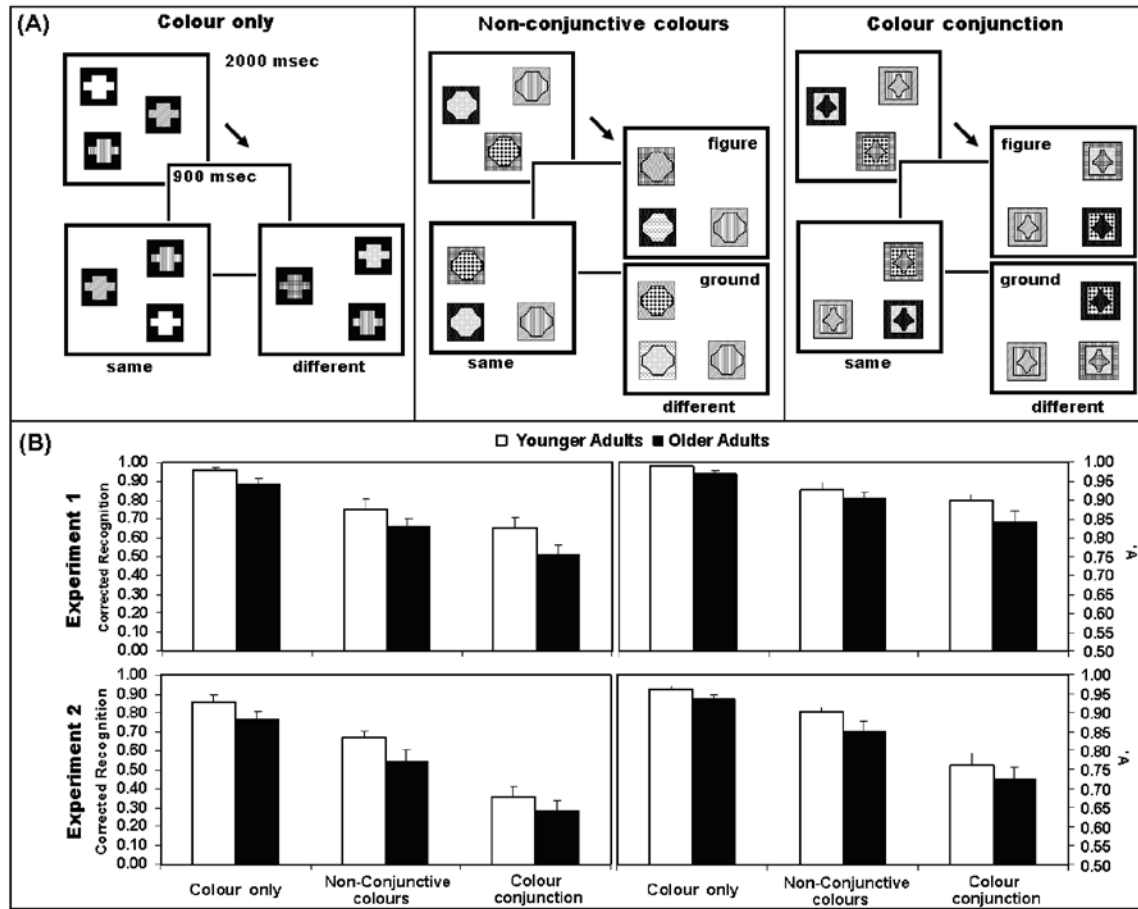
In the *colour only* (CO) condition the figure area displayed a different single colour for each of the three objects while the ground area was black for all. In the “different” trials the figure colour of each of two objects was replaced by a new different colour in each. No colours were repeated within a trial. In the *non-conjunctive colours* (nCC) condition both the figure and ground area of each object were shown in different colours. In the “different” trials one colour from either the figure or the ground area in

two of the objects was replaced by a new colour that had not appeared in the study display. Participants were told to focus on colours and not on their associations as the change would consist of new colours. In the condition assessing memory for *colour conjunction* (CC) both the figure and ground area were of different colours. In the “different” trials two objects swapped one colour either from the figure or ground area. Participants were told that colours and their associations were both relevant as sometimes colours would be rearranged in different combinations during the test display. For the nCC and CC conditions, colours could be repeated within a display no more than twice. Corrected recognition ($CR = \text{hit rate} - \text{false alarm rate}$) and change detection sensitivity (A') were computed and used for the analysis.

Results

CR was entered in a 2 (Group = young vs. older) x 3 (Condition = CO vs. nCC vs. CC) mixed-ANOVA. Mean data are shown in Fig.1B. Significant main effects were found for Group [$F(1,26) = 7.56, p < 0.05$] and for Condition [$F(2,52) = 38.30, p < 0.001$], but not for the interaction [$F(2,52) = 0.50, p = \text{n.s.}$]. Mean differences (MD) across conditions showed better performance in CO than in nCC [$MD = 0.21, p < 0.001$] and than in CC [$MD = 0.34, p < 0.001$]. Memory performance for CC was poorer than for nCC [$MD = 0.12, p < 0.05$].

Insert Fig. 1 - A and B - about here



For A' , significant main effects were found for Group [$F(1,26) = 5.78, p < 0.05$] and Condition [$F(2,52) = 20.34, p < 0.001$], but not for the interaction [$F(2,52) = 0.78, p = n.s.$]. A' was higher for CO than for nCC [MD = 0.06, $p < 0.001$] and CC [MD = 0.11, $p < 0.001$]. A' did not differ between nCC and CC [MD = 0.04, $p = n.s.$].

Discussion

Memory for bicoloured objects seems to be driven by the number of colours rather than by the number of objects. Luck and Vogel [17] suggested that bicoloured objects are

represented as single units in VSTM. However, their experiment did not assess binding explicitly as they used new colour values in the different trials (as in our nCC condition). Our results suggest that holding bound colours in VSTM results in a drop in memory performance as compared to holding single colours. Moreover, the results of the comparison between nCC and CC conditions (both presented with the same number of objects and colours) suggest that the binding of colours within bicoloured objects seems to be held in VSTM in addition to information about each colour. These effects were not explained by change detection sensitivity, nor were they modulated by age.

Therefore, we confirmed previous findings suggesting that remembering bicoloured objects is a more demanding task than remembering unicoloured objects. We also found that memory for multi-coloured objects is determined by the number of colours that VSTM can retain and this is true for both young and older participants. Finally, we found that age does not have a differential effect on each of the above manipulations but that there is an overall effect of age on memory performance.

Experiment 2

Although performance levels in Experiment 1 were below ceiling, they were still high, particularly in the unicolour condition. It might be possible that remembering 3 objects that were presented for 2000 msec resulted in a task that was not sufficiently demanding to be sensitive to the effects of age. In Experiment 2 we increased the number of objects in each array to 4 and reduced the presentation time by half. As a result, this experiment mirrored Experiment 2 reported by Brockmole et al. [14] with the only difference being

that here we assessed colour-colour binding rather than the colour-shape binding assessed in the earlier study. These experimental manipulations were therefore intended to increase the memory and perceptual load, hence increasing the sensitivity to any possible effects of ageing.

Methods

Twelve new young (age: $M=21.5$, $SD=1.9$) and older adults (age: $M=67.3$, $SD=5.9$) entered Experiment 2. The groups were matched for verbal IQ as measured by the WTAR (young: $M=110.7$, $SD=4.8$; older: $M=110.3$, $SD=4.9$). No health or colour vision problems were detected at the screening. All participants consented to take part in this study.

For Experiment 2 we used the same task described in Experiment 1. The only difference was that in Experiment 2 the arrays consisted of 4 objects and the study display was presented for 1000 msec.

Results

CR was entered in a 2 (Group = young vs. older) \times 3 (Condition = CO vs. nCC vs. CC) mixed-ANOVA. We found no effect of Group [$F(1,22) = 0.06$, $p = \text{n.s.}$], a significant effect of experimental Condition [$F(2,44) = 72.15$, $p < 0.001$], and no interaction [$F(2,44) = 0.21$, $p = \text{n.s.}$]. Performance in CO was better than in nCC [$MD = 0.21$, $p < 0.001$] and than in CC [$MD = 0.49$, $p < 0.001$]. Memory performance for CC was poorer than for nCC [$MD = 0.28$, $p < 0.05$] (Fig. 1B).

For A', no effect of Group was observed [$F(1,22) = 2.66$, $p = \text{n.s.}$]. The type of experimental Condition had a significant effect [$F(2,44) = 52.60$, $p < 0.001$]. No interaction between factors was found [$F(2,44) = 0.19$, $p = \text{n.s.}$]. A' was higher for CO than for nCC [MD = 0.07, $p < 0.001$] and CC [MD = 0.21, $p < 0.001$]. A' was poorer for CC than for nCC [MD = 0.13, $p < 0.001$].

Finally, given that the procedures in the two experiments were comparable we carried out a three-way mixed-ANOVA adding Experiment as a between-subjects factor to assess the impact of increasing cognitive demand in Experiment 2. Significant main effects were found for Experiment [CR: $F(1,48) = 27.06$, $p < 0.001$; A': $F(1,48) = 26.22$, $p < 0.001$], Group [CR: $F(1,48) = 10.64$, $p < 0.001$; A': $F(1,48) = 7.42$, $p < 0.01$], and type of experimental Condition [CR: $F(2,96) = 106.6$, $p < 0.001$; A': $F(2,96) = 71.81$, $p < 0.001$]. There was no Group by Experiment [CR: $F(1,48) = 0.02$, $p = \text{n.s.}$; A': $F(1,48) = 0.03$, $p = \text{n.s.}$] or Group by Experiment by Condition interaction [CR: $F(2,96) = 0.52$, $p = \text{n.s.}$; A': $F(2,96) = 0.65$, $p = \text{n.s.}$]. Experiment significantly interacted with Condition [CR: $F(2,96) = 5.13$, $p < 0.05$; A': $F(2,96) = 8.51$, $p < 0.001$] suggesting that the experimental manipulations impacted more on performance in the CC condition, but to the same extent in both groups.

Discussion

When the task was made more cognitively demanding, no effect of age was found. The lack of group by condition interaction observed in Experiment 1 was replicated in this new experiment. The results of the three-way ANOVA suggest that the experimental

manipulation affected both groups to the same extent. This gives further support to the hypothesis that age does not affect STM for bound surface features [14].

General Discussion

The lack of an age-related effect on binding within the colour dimension reported here is in striking contrast with previous studies which have indicated that age differentially impairs long-term representations of bound features in a non-material specific way [3,5,7,8], or short-term representations involving objects bound to locations intentionally encoded [10,11]. The present experiments suggest that the lack of an age-related effect applies to within-dimension feature binding in VSTM, complementing previous results showing a similar lack of an age-related effect on binding within the location dimension (locations to locations [13]), or between dimensions (shapes to colours [14], or items to locations incidentally encoded [13]).

There is a discrepancy between the lack of age-effects on VSTM binding of surface features intentionally encoded observed in the current and in a previous study [14], and the age-effects on STM binding of item-location intentionally encoded found by other authors [10-12]. Our stimuli possess gestalt principles (e.g. closure, figure and ground) as well as physical properties (e.g. angles and sides) that make each object shape look different from other object shapes in the experiment, a role that location cannot play [20-22]. It has been shown that in order to perform a face matching task (in which the binding of features aids object identification) at the same level of accuracy as the young, older people have to recruit supplementary areas outside of the visual ventral stream [23].

On the other hand, the frontal lobes, which are important for spatial representation [24], have been found to be hypoactive in older adults during STM tasks assessing intentional encoding of item-location binding [10,11]. Hence it is possible that functional reorganisation may help to maintain performance during the binding of features that enable object identification in older adults, although do not prevent performance impairments when binding objects to location.

Difficulties in short-term binding of item-location have been observed in older adults using sequential [10,11] or simultaneous presentation [12], common objects, words [10,11], or colours [12], retention intervals of 1 sec [10,12] or 8 seconds [11], single [12] or whole display probes [3], change detection [12] or forced-choice recognition tasks [3,10]. On the other hand, the lack of age-effects on VSTM binding reported here have been observed using change detection or recall tasks [14], delays of 900 msec or 5 sec [14], single or whole display probes [14]. Hence, methodological factors do not seem to be underpinning the lack of age effects reported here. Further research will help to elucidate whether these age-related short-term binding problems appearing when location is intentionally encoded also extend to other forms of between-dimension binding (e.g. faces-names).

The lack of age-effects on within-dimension feature binding in VSTM found in the current study is in line with the outcome of an earlier study [13]. In both studies intentional encoding of features was assessed, along with similar set sizes and very short retention intervals. However, the current study assessed binding within the colour dimension while the earlier study [13] assessed binding within the location dimension. One possible explanation for this preserved function may stem from the fact that, under

intentional encoding conditions, forming transient bindings of features within the same visual pathways (e.g., coloured objects in the ventral stream or spatial configurations in the dorsal stream) may be less vulnerable to the effects of age than binding across visual pathways (e.g., objects to locations). As discussed above, older people show patterns of brain activation different from the young while they integrate information that helps to identify faces [23] (see also Chen, Myerson, and Hale, 2002 [25]). Moreover, the hippocampus, a structure important for binding between dimensions, is affected by ageing [11] whereas parahippocampal regions (i.e. perirhinal and entorhinal cortices), which are important for binding features within dimension [26], are not [27]. The fact that these structures have been found to subserve binding operations in VSTM [28] would help to explain our current and earlier findings [13,14].

However, Olson et al. [13] reported no age-effects on STM for object-location binding when location was incidentally encoded. It is known that automatic memory processing (i.e. incidental learning) is less vulnerable to the effects of age [29]. Remembering two letters intentionally and their locations incidentally may not be sufficiently demanding to be sensitive to the effects of age. When the cognitive demand increases, older people have difficulties in remembering objects' location even if location is incidentally encoded [5]. Thus, age-related difficulties are more likely to show on tasks that demand greater cognitive effort [30].

Finally, we found that performance was poorer in memory for bicoloured objects than for unicoloured objects whereas Brockmole et al. [14] found that memory for shape-colour conjunctions was not poorer than memory for shapes alone. In both cases however, these effects were not modified by age. Whereas a shape-colour conjunction

may be processed as a unique entity, a coloured figure over a coloured ground may be processed as independent entities sharing the same visual space. Therefore, the cost of holding bicoloured objects in memory would reflect an extra capacity required to retain the relatedness of two integrated objects (i.e. figure + colour and ground + colour). Participants in the study by Wheeler and Treisman [15] reported that they had remembered the inside and outside of bicoloured squares not as parts of one unit but as two separate entities. The issue regarding between or within feature bindings would be an interesting development for future studies.

In conclusion, the evidence presented here suggests that the age effect on memory for conjunctions of features in multi-feature arrays depends on (1) whether the material has to be held over brief periods of time or is the basis for forming longer term representations, (2) whether features are processed within or between feature dimensions, (3) and on whether the result of these binding operations yields to object identification. We propose that older adults' ability to form temporary short-term bindings of features that are processed within the same dimension is preserved whenever these features serve to define the identity of complex objects. Future research should address the differential vulnerability of VSTM and LTM for bound features and the effect of age.

Figure Captions

Fig.1. (A) Events and time course for a single trial for each of three experimental conditions using three examples of object shapes. (B) Corrected recognition and A' for Experiments 1 and 2 during the three experimental conditions in both young and older adults (error bars = standard errors of the mean).

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